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FINAL REPORT for grants NAGW-1930, NAGW-1934 and NAGW-1954

1 Introduction

These grants were issued for a collaborative effort by C. J. Waddington (University of Minnesota), E. C. Stone, (California Institute of Technology) and M. H. Israel, J. Klarmann and W. R. Binns (Washington University to continue the analysis of data from the Heavy Nuclei Experiment (HNE), flown on the HEAO-3 mission. The HNE was designed to measure the elemental abundances of relativistic cosmic ray nuclei covering the charge range $17 \leq Z \leq 130$. The result of these measurements is significant to the study of nucleosynthesis, the origin, acceleration and propagation of cosmic ray nuclei and the properties of the interstellar medium. A description of the instrument is given in [1]. Previously the data analysis had been supported by grants NAG8-498, NAG8-500 and NAG8-502 from MSFC after expiration of the original contracts.

2 Analysis of data from HEAO-3

2.1 Elemental abundances of ultraheavy cosmic rays

During the period of these contracts we completed the analysis of the elemental composition of the heavy nuclei in the cosmic radiation. We found agreement, within the quoted errors, with the data from the Ariel satellite [2], and combined them in our reference [3]. These results, which were also presented at the 21st International Cosmic Ray Conference in Adelaide [4], were then propagated to the source and compared with the solar system abundances of Anders and Ebihara [5]. The results show that the cosmic ray abundances agree well with solar system abundances up to $\approx Z = 60$, but that for higher charges an enhancement by a factor of ≈ 2 in r-process is apparent in the cosmic radiation.

2.2 Energy spectra for $18 \leq Z \leq 28$

We have revised our previous analysis [6] of the data set utilizing the relativistic rise of the signal in ion chambers with energy to deduce the energy spectrum. The new results incorporated recent data on fragmentation cross sections and used improved values for the standard deviations of the observed signal. The results did not differ from the original data sufficiently to warrant publication, but were presented at the Adelaide conference [7].

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3 Heavy ion exposures at the Bevalac

The interpretation of the HEAO-HNE data requires a knowledge of both the response of its detectors to heavy ions and the consequences of the interaction of cosmic ray particles with the interstellar, and detector, materials. For this purpose we exposed an array of Cherenkov and Ion chamber detectors, similar to the HNE detector to various heavy Ion beams at the LBL Bevalac accelerator. Such exposures were carried out in November 1986, and May 1990.

The results achieved so far have enabled us to obtain a new grant to continue the study of fragmentation cross sections.

3.1 Response of ion chambers and Cherenkov counters to heavy ions

An analysis of the signals observed in the ion chambers and Cherenkov counters showed no first order deviation from a Z^2 dependence in varying the projectile from ^{26}Fe through ^{57}La and ^{67}Ho to ^{79}Au [8]. The observed signals were strongly dependent on the secondary electrons produced by the primary particles in traversing the various elements of the detector. Thus the signal at varying depth into the detector changed markedly. Hence further analysis of the data would have a bearing solely on the response of our specific detector which was used for the accelerator runs alone and was not pursued.

3.2 Response of scintillators to heavy ions

In order to evaluate options for a follow-up to the HEAO-IINE experiment we exposed two different scintillators to ions of silver and its secondaries during our May-1990 run. The results showed a charge resolution of 0.25 charge units in the range ^{31}Ga to ^{47}Ag [9] for both acrylic and NE-114 scintillators. If future exposures of scintillators to beams of heavier ions show the same adequate resolution, this result shows that scintillators are a useful component of future investigations into the composition of heavy cosmic rays.

3.3 Heavy ion fragmentation cross-sections

The main purpose of our accelerator exposures was the determination of the fragmentation cross-sections for heavy cosmic rays. We have exposed our detectors to beams of ^{26}Fe , ^{36}Kr , ^{47}Ag , ^{54}Xe , ^{57}La , ^{67}Ho and ^{79}Au at energies ranging from just below Cherenkov cutoff to a maximum which varied from ≈ 2 GeV/n at iron to 900 MeV/n at gold. The targets that these projectiles fragmented on were: carbon and polyethylene, from which the cross sections for hydrogen were deduced, as well as Li, Al, Cu, Sn and Pb. We have been able to fit 796 cross sections on heavy targets with a seven parameter fit to within 7 on hydrogen targets with a different fit [10,11,12]. These results have also lead

to the Ph.D thesis of J. R. Cummings [13]. The total charge changing cross-section for Kr projectiles was reported at the Dublin ICRC [14], the analysis of the May 1990 exposures is still in progress and will lead to the Ph.D. thesis of B. S. Nilsen.

4 Future work

As part of our efforts we have been able to propose a cost effective future mission to continue the study of the Ultra Heavy Cosmic Rays [15]. Such a mission would be capable of determining the age of the cosmic rays by a direct measurement of the uranium/thorium ratio and resolve the ambiguities left by the HEAO-HNE mission with much improved charge resolution.

The work to study the fragmentation cross sections is continuing under a new NASA grant and has led to a new exposure of our instrument to gold projectiles of ≈ 15 GeV/n.

References

- [1] W. R. Binns, M. H. Israel, J. Klarmann, W. R. Scarlett, E. C. Stone, and C. J. Waddington (1981) The UH-nuclei cosmic ray detector on the third high energy astronomy observatory. *Nucl. Inst. Meth.* **185**, 415.
- [2] P. H. Fowler, R. N. Walker, M. R. W. Mashed, R. T. Moses, A. Worley and A. M. Gay (1987) *Ap. J.*, **314**, 739.
- [3] W. R. Binns, T. L. Garrard, P. S. Gibner, M. H. Israel, M. P. Kertzman, J. Klarmann, B. J. Newport, E. C. Stone, and C. J. Waddington (1989) The Abundances of Ultraheavy Elements in the Cosmic Radiation: Results from HEAO-3. *Ap. J.*, **346**, 997.
- [4] T. L. Garrard, M. H. Israel, J. Klarmann, E. C. Stone, C. J. Waddington, W. R. Binns (1990) Cosmic Ray Elemental Abundances for $26 \leq Z \leq 40$ Measured on HEAO-3. *21st Int. Cosmic Ray Conf.*, **3**, 61.
- [5] E. Anders and M. Ebihara, (1982) *Geochim Cosmochim. Acta*, **46**, 2363.
- [6] W. R. Binns, T. L. Garrard, M. H. Israel, M. D. Jones, M. P. Kamionkowski, J. Klarmann, E. C. Stone, and C. J. Waddington, (1988), *Ap. J.*, **324**, 1106.
- [7] V. Vylet, C. J. Waddington, W. R. Binns, T. L. Garrard, M. H. Israel, J. Klarmann, M. Metzger (1990) Energy Spectra between 10 and Several Hundred GeV/Nucleon for Elements From ^{18}Ar to ^{23}V : Results from HEAO-3. *21st Int Cosmic Ray Conf.*, **3**, 19.

- [8] J. Klarmann, V. Vylet, C. J. Waddington, W. R. Binns, T. L. Garrard, M. H. Israel (1990) Response of Ionization Chambers and Cherenkov Counters to Relativistic Ultraheavy Nuclei. *21st Int. Cosmic Ray Conf.*, **4**, 434.
- [9] W. R. Binns, D. J. Crary, J. R. Cummings, T. L. Garrard, J. Klarmann, B. S. Nilsen and C. J. Waddington (1992), Response of Scintillators to UH Nuclei, *22nd Int. Cosmic Ray Conf.*, **2**, 511.
- [10] J. R. Cummings, W. R. Binns, T. L. Garrard, M. H. Israel, J. Klarmann, E. C. Stone, C. J. Waddington (1990) Determinations of the cross sections for the production of fragments from relativistic nucleus-nucleus interactions. I. Measurements. *Phys. Rev. C*, **42**, 2508.
- [11] J. R. Cummings, W. R. Binns, T. L. Garrard, M. H. Israel, J. Klarmann, E. C. Stone, C. J. Waddington (1990) Determinations of the cross sections for the production of fragments from relativistic nucleus-nucleus interactions. II. Parametric fits *Phys. Rev. C*, **42**, 2530.
- [12] J. R. Cummings, T. L. Garrard, M. H. Israel, J. Klarmann, E. C. Stone, C. J. Waddington, W. R. Binns (1990) Global Representation of the Cross Sections for the Production of Fragments of UH Nuclei. *21st Int. Cosmic Ray Conf.*, **3**, 416.
- [13] J. R. Cummings, (1989), Fragmentation of Relativistic Heavy Nuclei with Application to Cosmic Ray Propagation, Ph.D. thesis, University of Minnesota.
- [14] C. J. Waddington, W. R. Binns, J. R. Cummings, T. L. Garrard, J. Klarmann, R. A. Mewaldt and B. S. Nilsen (1992), Fragmentation of UH Nuclei, *22nd Int. Cosmic Ray Conf.*, **2**, 288.
- [15] W. R. Binns, T. L. Garrard, L. Y. Geer, J. Klarmann, R. A. Mewaldt and C. J. Waddington (1992), UHCR: A Cosmic Ray Mission to study Nuclei in the Charge Range from $20 \leq Z \leq 100$. *22nd Int. Cosmic Ray Conf.*, **2**, 507.